ELECTRICAL PROPERTIES OF THIN NANOCRYSTALLINE DIAMOND BASED STRUCTURES

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Keywords: nanocrystalline diamond, thin films, diodes, electrical properties.

Abstract

Electronic structures based on thin films of nanocrystalline diamond are described as well as their electrical properties. Polycrystalline diamond films with thickness between 0.25 μm and 1.0 μm and with average grain sizes of 300 nm and less are formed by microwave plasma assisted chemical vapor deposition. Electrical properties of free standing diamond films and of substrate mounted films are measured over a wide range of voltages with two-terminal electrical contacts to the growth side and nucleation side of the film. Depending on the type of electrical contacts, the rectification ratios of two-terminal structures range from 1 to 11,000.

INTRODUCTION

Thin diamond membranes and free-standing sheets are of interest for a variety of potential applications. A recent report has described methods for obtaining flexible free-standing diamond films that can be applied to a variety of substrates, and mechanical properties of such films.[1] Given the potential advantages of diamond for electronics, such diamond films may be considered as flexible materials for electronic applications. This paper describes initial experiments on the electrical properties of structures based on these films.

EXPERIMENTAL METHODS

The undoped diamond films were deposited by microwave plasma assisted chemical vapor deposition on p-type silicon wafers that had been nucleated by polishing with diamond powder. The resulting film thickness ranged from 0.25μm to 1 μm and rms surface roughness values ranged from approximately 15 nm to 25 nm. After diamond deposition, post processing was used to form 2-terminal electrical structures with one electrical contact on the growth side and the other on the nucleation side of the film.

Metallization studies in this work included indium, gold, titanium/gold, graphite based paint, zirconium, silicon, and pressure contacts against tungsten, platinum, and stainless steel. A variety of sample configurations were investigated. Metallization was performed on diamond film supported on the original silicon substrate and also on free-standing diamond. For the latter, the silicon substrate was removed by back etching and the diamond film was transferred to a different structure. An example of a two terminal structure using a free-standing diamond film is shown in Fig. 1. In this case, metallization on both sides of the film is by means of semi-transparent gold contact and the diamond film is approximately 1 μm thick.

RESULTS

The current voltage characteristics of structures such as shown in Fig. 1 are symmetrical, or nearly symmetrical for positive and negative voltages. At low electric fields the characteristics are linear with a slope corresponding to a conductivity of 1.1 x 10^{-11} $(\Omega\text{-cm})^{-1}$. At high electric fields, the conductance is electric field activated and well-modeled by the Poole-Frenkel equation as

$$\sigma = \sigma_{00} + \sigma_0 e^{\alpha E} \qquad [1]$$

with σ_{00} = 1.1 x 10^{-11} $(\Omega\text{-cm})^{-1}$ and $\alpha = 1.0 \times 10^{-5}$ cm/V. Thus, while the structure is highly resistive at low applied bias, appreciable current can flow at higher biases.

Fig. 2 shows an example of the current-voltage characteristics for a rectifying device, in this case a structure with a Zr contact (diameter = 450 μm) on the growth surface of a 0.25 μm thick diamond film still attached to the p-type silicon substrate. With negative voltage on the Si electrode, small reverse-biased currents are observed. With sufficient positive voltage on the Si electrode the field activated conductance is sufficient to allow appreciable forward current with a rectification ratio ($I_{FORWARD}/I_{REVERSE}$) of 1.1 x 10^4 at a bias of 80 V. The saturation at 20 mA seen in Fig. 2 is due to the current limitations of the measuring device.

SUMMARY

Two terminal electric structures that incorporate undoped nanocrystalline diamond have been investigated with symmetric and asymmetric electrodes and with free-standing films and substrate attached films. With rectifying electrodes, significant rectification ratios can be observed at high bias due to field activated conduction in the diamond.

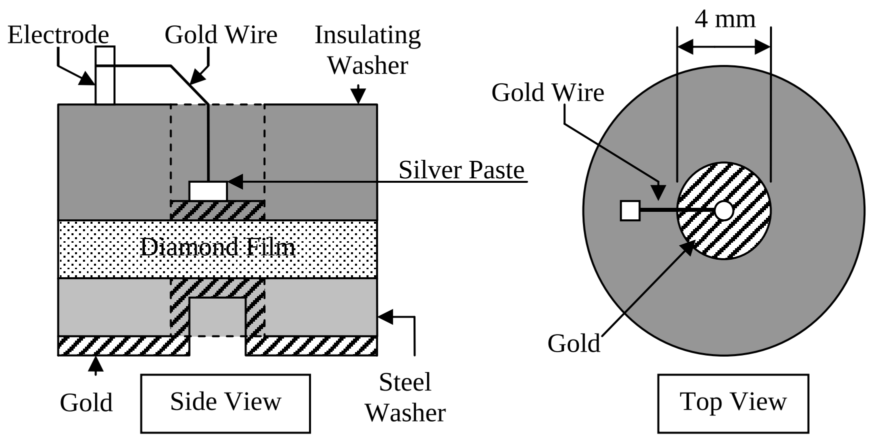

Figure 1. Example of free-standing, diamond film structure with symmetric gold contacts.

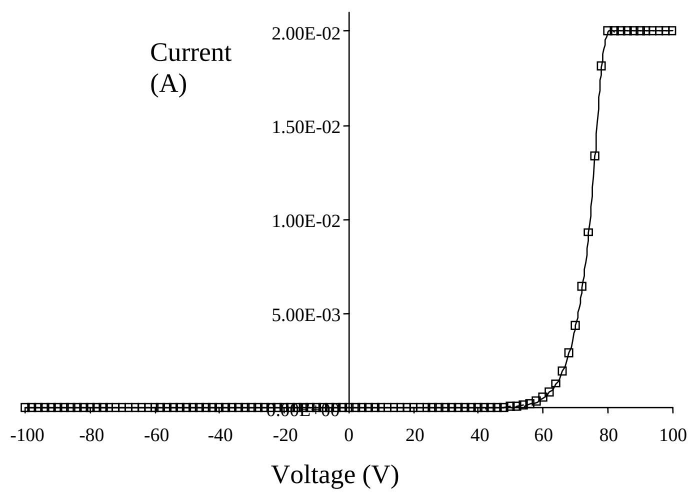

Figure 2. Example of current-voltage characteristics of a rectifying structure with asymmetric contacts consisting of Zr/diamond/Si (positive polarity relative to silicon).

REFERENCES

1. Reinhard, D. K., et al. “Fabrication and Properties of unltranano, nano, and microcrystallilne diamond membranes and sheets”, *J. Vac. Sci. Tech. B,* in press.